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Gradient effect of road transportation on economic development in different geomorphic regions

YANG Xue-ting[1,2] http://orcid.org/0000-0003-4633-2185; e-mail: cheerxueting@126.com

FANG Yi-ping[1,3*] http://orcid.org/0000-0002-9695-6933; e-mail: ypfang@imde.ac.cn

QIU Xiao-ping[1,2] http://orcid.org/0000-0001-6310-5959; e-mail: qiu_xiaoping@foxmail.com

ZHU Fu-biao[1,2] http://orcid.org/0000-0002-4606-3336; e-mail: zhufub@163.com

* *Corresponding author*

1 Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, Chengdu 610041, China

2 University of Chinese Academy of Sciences, Beijing 100049, China

3 College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100190, China

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Abstract: The economic benefits of transport infrastructure investment have been widely accepted. However, the varying influence of road transport development across vertical space has rarely been discussed. Taking Sichuan province in China as case study area where the landform is diverse and complex, administrative counties were categorized into 4 main types: plain counties, hill counties, mountain counties, and plateau counties. Using statistical data during 2006-2014, the performance of economic development and transport construction level in the four types of counties are discussed. Subsequently, the heterogeneous effect of each grade road on economy was calculated by local regression model (GWR). The results indicate that plain counties largely surpassed the other geomorphic counties in economic development level, while the gradient gap among them was on the decline. Similarly, distribution of transport infrastructure presented a decreasing trend from the low plain counties to high plateau counties. Regional imbalances were mainly reflected in the County road and Village road. Regarding the changes of regional gaps, National & Provincial roads and County roads were constantly expanding, whereas the disparity of Village road was slowly narrowing over time. Particularly noteworthy was the non-stationary economic influence of traffic factors across vertical gradients. On average, National & Provincial roads generated higher benefits in the high elevation regions than the lowlands. In contrast, County road and Village road were found to be more effective in promoting economic development in plains. With regard to local estimates of traffic factors, coefficients in mountain counties exhibited larger fluctuation ranges than other geomorphic units. The conclusions provide a basis for government decision-making in a more reasonable construction arrangement of road facilities and sustainable economic development.

Keywords: Geomorphic counties; Road transportation; Economic development; Geographically weighted regression; Gradient variation

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Introduction

China's economy has developed rapidly in last decades. Such rapid development has presented obvious spatial imbalance; as well, regional economic disparity has become a major factor restricting China's comprehensive sustainable development (Jiang et al. 2014). Apparently, it is a major concern of the national and local governments as well as scholars at the present stage (Guan et al. 2012). Apart from spatial disequilibrium among the Eastern, Central and Western Regions (Aguignier 1978; Yang 1990; Wu 2013), urban and rural areas (Ming and Zhao 2006; Sicular et al. 2007), China also has experienced growing inequality between mountainous regions and lowlands. The lagging economic development of the mountainous areas has become an important reason for the continuous expansion of the overall regional disparity in China (Chen 2004). According to empirical analyses, significant discrepancy along the altitude gradients has been found in the economic indicators, like industrial agglomeration index (Zhai et al. 2012), income for farmers (Fang et al. 2012; Fan and Li 2008) and economic development level (Ying et al. 2014). Fan and Li (2008) have found that terrain conditions have an impact on farmers' behaviors which affects their income. Li has argued that topography has great effect on per capita income in agricultural areas (Li et al. 2008). Zheng et al. (2012) pointed out that with a 1% increase in the logarithm value of altitude, the regional economic growth rate decreases by 0.845%. On the basis of the spatial partitioning of the geomorphologic morphology of Jiangxi Province, Zhong et al. (2009) have seen that per capita GDP growth is characterized by plains > hills > mountain areas. The economic growth rate of mountainous areas in China has been at a low level for a long time, especially in the western mountainous areas, which are characterized by fragile ecological environment, frequent disasters, lagging development infrastructure, and poor economic base. Compared with the plains, transportation construction is the bottleneck restricting the rapid development of economy and become a crucial factor of serious poverty in mountainous areas. In particular, the construction, operation and management of transportation lines are greatly impeded by the natural terrain, further expanding the "regional gap" between the mountainous areas and the outside world.

Numerous studies have been conducted on the relationships between transport infrastructure and economic growth in the past decades since the seminal work of Aschauer (1989), and positive correlations between them is now commonly accepted (Berechman et al. 2006). The major aspects and advances in this field include: (1) The dynamic relationship between transportation and economic development. Banister and Berechman (2001) proposed a scheme for the coupling of transport and economic growth. They proposed that improvement of transport infrastructure investment accelerate economic growth via travel effects, primary benefits and allocative externalities. Lakshmanan (2011) developed general equilibrium linkages of transport-economy, he pointed out that transport improvements open up markets and create conditions. Inevitably a variety of agglomeration economies and endogenous growth effects follow by (Lakshmannan and Anderson 2007), thus influencing economic structure and performance. Rietveld (1989) revealed that extension of transport infrastructure exerts impact on both production and household consumption. In the short run, it leads to a reduction of transportation costs and times. In the long-run, improvements in resident income, employment, and new investment opportunities are induced by the growth of traffic infrastructure. (2) The output elasticity of transport investment at various levels. Berechman et al. (2006) explored the relationships between transportation capital development and economic activity at the state, county and municipality level, they ascertained that the impact of highway capital on economic growth become smaller as the geographic focus narrowed. By employing C-D production function with time series data, Munnell (1990) obtained output elasticity for traffic capital of 0.33, while the estimate for the state was 0.15. Ozbay et al. (2003) applied pooled data for counties found an average elasticity of 0.09, further certified the varied productivity effects of transport infrastructure at different scales. (3) Returns of transit investments in different types. The overwhelming majority of scholars focus on highway traffic systems (Mihic et al. 2011; John et al. 2009), while others put much emphasis on the economic effect from railroads (Atack et al. 2010), airline (Chi and Baek 2013), waterway (Clark et al. 2004). Hong et al. (2011) probed into the relationships between economic growth and different kinds of transport infrastructure. (4) Spillover effects generated by transport infrastructure. With the development of spatial econometrics (Anselin 2001; LeSage and Pace 2009), spatial externalities of transport infrastructure received more attention. Based on an econometric model, Berechman et al. (2006) found that spillovers exist at the municipality level while the effects were not obvious as the geographical area gets larger. According to county level data from 1990-2000 in the New York/New Jersey metropolitan area, Ozbay et al. (2007) pointed out spillover effects of highway investment tend to decrease as the distance increases. Gutiérrez et al. (2010) creatively monetized the spillover effects of transport infrastructure investment through the network analysis of a GIS model.

A host of studies have been focused on these issues in China (S Démurger 2001; Yu et al. 2012, 2013; Deng et al. 2014; Jiao et al. 2014; Cao et al. 2015), study area mainly be selected in the eastern developed region. In the year of 2000, China's government publically announced the Western Region Development Strategy, which intends to address economic, infrastructure, and social development concerns in the poor west, aiming at promote the common development of the whole country. Since then, more financial supports poured into the west, and the central government placed priority in a plan to stimulate investment in road facilities, particularly high-grade roads in western areas (Fan et al. 2008). In 2014, for example, over 30 major projects were launched to improve transportation in western China. These projects aimed at expanding the road network and linking all counties with highways (Fan and Chan-Kang 2008). The economic efficiency of producing road service in western China (Wu 2008; Liu et al. 2009; Wang et al. 2010) as well as poor mountains (Liu et al. 2011; Wang et al. 2016; Wang et al. 2015, 2016) has been gradually studied in depth.

In summary, the existing research shows the following characteristics: Firstly, quantitative approach has been updated from traditional regression models to the spatial econometric means. Secondly, study areas have undergone a transition process from the whole country to small scale regions. Thirdly, comparative research on the spatially varying relationships between economic development and different types of transport infrastructure is emerging in recent years. Lastly, the equilibrium deployment of transport infrastructure in the backward areas and poor areas is becoming gradually stressed.

The current correlative literatures provide a lot of inspiration, but some important gaps still remained. Firstly, different quality of roads has very different economic returns, which few scholars have mentioned (Fan and Chan-Kang 2008). Secondly, with the evolution of spatial econometrics, spatial non-stationarity and heterogeneity have been taken into account (Qiu et al. 2012; Páez 2015). However, discussion on the spatial variation focused on economic zones classified by socio-economic characteristics while geomorphic units have rarely been addressed. Thirdly, GDP or the rural resident net income per capita is usually selected as the proxy of economic level to measure the effect of transport facilities. Single indicators have difficulties in reflecting economic development capacity.

Given these lacunae, the study focused on the impact of road grades on economic development across different vertical gradients, and thus we classified road infrastructure into three classes and divided the study area into four major geomorphic counties. The spatial relationship was measured by geographically weighted regression model, based on county level data in Sichuan province for the "11th Five-Year Plan" (2006-2010) and the "12th Five-Year Plan" (2011-2015) periods. Such information can assist policy makers in targeting their transportation investments more effectively, so as to promote economic development and reduce regional disparities.

1 Study Methods

Sichuan province is located in the southwest of China and includes 21 cities (prefectures). It covers an area nearly half a million square kilometers, equivalent to the area of the largest country in Western Europe, France. It borders the Qinghai–Tibet plateau on the west and the Yangtze plain on the east. Thus, topography in Sichuan province is vastly diversified, the varied elevations ranging from 298 m to 4500m. Based on the topography classification of China (Fang et al. 2016), counties in Sichuan province are categorized into 4 main types: plain counties, hill counties, mountain counties and plateau counties (Figure 1 and Table 1).

As an important province in western China, the GDP per capital in Sichuan province in 2014 was 32,588 RMB and the net income per capita for farmers was 9199 RMB, increasing at the rate of 14.34% and 12.35% per year respectively, higher than the national average. Since the implementation of the Western China development strategy, the construction of traffic infrastructure has been emphasized in the entire province. By the end of 2014, there was $30.97×10^4$ km of road mileage in Sichuan province, with a road density of 63.72 km/10^2 km^2.

1.1 Measurement of economic development

County economy is an important part of regional economy in China, and its coordinated development is of great significance for optimizing the allocation of resources and enhancing the regional competitiveness (Fang et al. 2013). The traditional evaluation indicator of county economic development mainly applied aggregate indicator (Meng et al. 2014) or the average indicator (Zhou et al. 2014; Chen et al. 2017). There are many limitations in the single indicator evaluation method, which is not enough to fully reflect the overall development situation of the economy, and furthermore not conducive to the transformation of

Table 1 Description of each geographical county in Sichuan province, China in 2014

Types	Units		Average Elevation (m)	Population density (person/km^2)	Economic density (RMB /person)	Road density (km/10^2 km^2)
	Areas (10^4 km^2)	Share				
Plain counties	4.31	8.87%	446	1587	46300	185
Hill counties	5.74	11.81%	460	591	27090	161
Mountain counties	36.69	75.49%	2311	170	27958	64
Plateau counties	1.86	3.83%	3631	6	19989	12

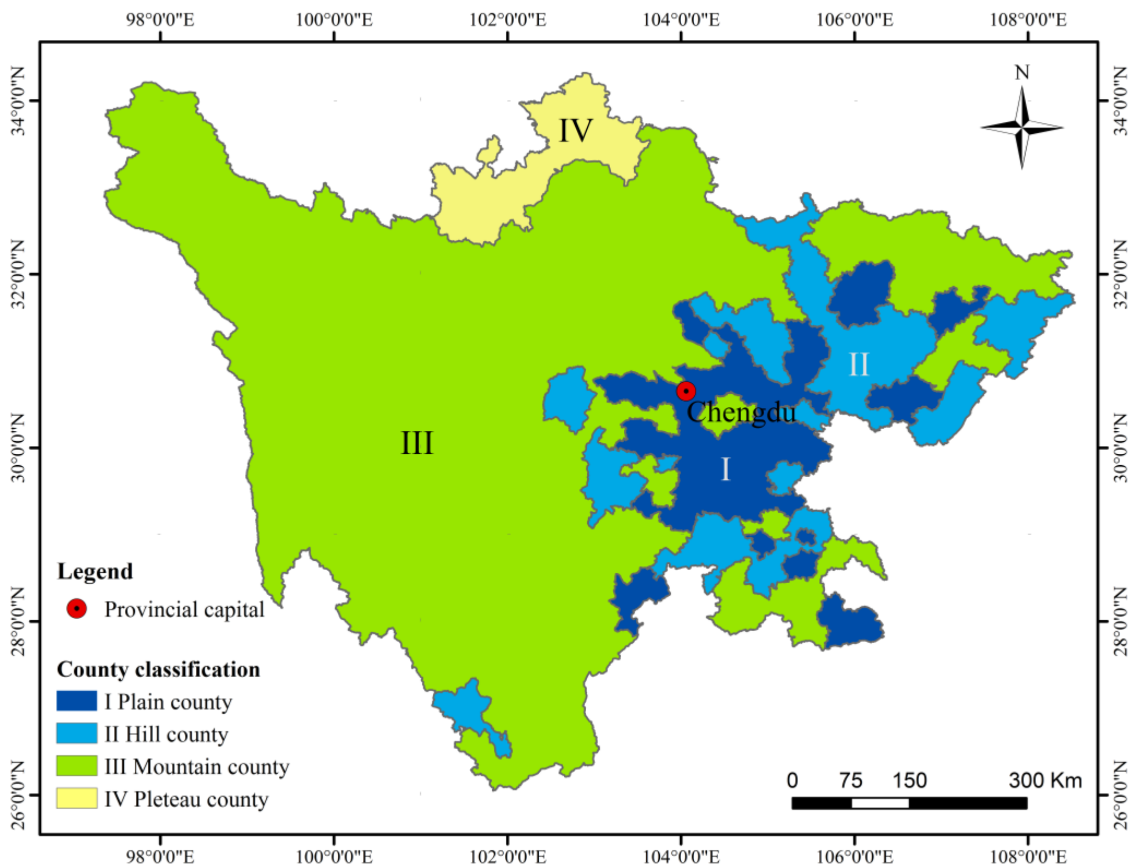

Figure 1 The categories of county and distribution in Sichuan province, China.

the growth mode or the new countryside construction (Du et al. 2014). Therefore some scholars adopted the composite economic index to measure the development level of county economy (Du et al. 2014; Liu et al. 2012). Based on the principle of the systematic comprehensiveness, comparability, representation and the data availability, this paper mainly refers to the research on China's mountainous economic classification evaluation by Fang (Fang et al. 2016). The composite economic index was assessed using three parameters: economic base, resident income and economic potential of regions. In this study, eight indicators were selected as important criterion (Table 2). On the basis of data standardization, composite economic index was achieved by means of entropy and linear weighting methods, so as to reflect the current situation of the economic development of 181 districts and counties in Sichuan Province.

$$E_i = \sum_{j=1}^{n}(W_{ij} \times X'_{ij}) \tag{1}$$

where, X'_{ij} refers to the standardized value of each indicator, W_{ij} is the weights of indicators, n represents the total number of features. E_i is the composite economic index, the value of index range between 0 and 1, the greater E_i is, the higher economic development level it has.

1.2 Econometric model of the economic impacts of road transport infrastructure

The close relationship between transportation and regional economy has been extensively recognized. In order to explore and compare the effects of transportation in different grades on the regional economic development, we just select the crucial road transportation factors as independent variables, but it does not mean that transportation is the only factor determining regional economic development.

Ordinary least squares regression (OLS) and geographically weighted regression (GWR) were used to investigate the relationships between economic development and traffic driving factors.

1.2.1 OLS regression

OLS as the global multivariate regression model assumes the variables have homogeneity over the whole study area before analyzing, resulting the average state with just one equation for all data (Gilbert et al. 2010). It can be formulated as:

$$y_i = \beta_0 + \sum_{i=1}^{k}\beta_k x_{ik} + \varepsilon_i \tag{2}$$

where, y_i is the estimated value of composite economic index, β_0 represents intercept, x_{ik} defines three inputs, that is the density of National & Provincial road, County road and Village road, β_k expresses the coefficient of road in different grades, ε denotes the error term.

1.2.2 GWR regression

The geographically weighted regression (GWR) model is an extension of OLS model, which is improved by composing geo-referenced data obtained from the geographically weighted matrix W (Fotheringham et al. 2000, 2002; Lin and Wen 2011). According to each observation point, the model generates a separate regression equation and thus the non-stationarity in the relationship between dependent and independent variables can be assessed (Alexander et al. 2013), the above model can be rewritten as:

$$y_i = \beta_0(u_i, v_i) + \sum_{i=1}^{k}\beta_k(u_i, v_i)\, x_{ik} + \varepsilon_i \tag{3}$$

where, $\beta_0(u_i, v_i)$ expresses the intercept for location i, $\beta_k(u_i, v_i)$ is the local parameter estimate for independent variable x_k at location i.

Table 2 Measuring indicators for economic development and weight

Target layer	Principle layer	Element layer	Weight	
			"11th Five-Year Plan"	" 12th Five-Year Plan"
Composite economic index	Economic base	GDP per capital (RMB/person)	0.13	0.124
		Average financial income(RMB/person)	0.264	0.282
		Share of the non-agricultural sector in total GDP (%)	0.033	0.026
	Resident income	per capita net income of rural residents (RMB/person)	0.091	0.098
		per capita disposable income of urban resident (RMB/person)	0.039	0.052
	Economic potential	Total retail sales of consumer goods per capita (RMB/person)	0.249	0.258
		Total social fixed assets investment per capita (RMB/person)	0.186	0.144
		Fiscal deficit per capita of local government (RMB/person)	0.008	0.016

According to Tobler's first law of geography, near things are more related than distant things (Tobler 1970). The observations closer to point i have more impact on the local parameter estimates for the location, the parameters are solved by the following matrix form Eq. (4):

$$\hat{\beta}(u,v) = (X^T W(u,v)X)^{-1} X^T W(u,v)y \quad (4)$$

where $\hat{\beta}(u,v)$ is the unbiased estimate of β, $W(u,v)$ denotes the weighting matrix. In this study, the adaptive bi-square kernel was selected, where the weight of observation j to the ith regression point was estimated by:

$$W_{ij} = \begin{cases} [1-(\frac{d_{ij}}{d_{max}})^2]^2 & d_{ij} \le b \\ 0 & d_{ij} > b \end{cases} \quad (5)$$

where w_{ij} represents the weight of observation, d_{ij} is the Euclidean distance between the two observation sites i and j, d_{max} is the max distance from the mth farthest county to the regression county (m is the selected optimal neighboring counties).

1.2.3 Comparison between OLS and GWR

In order to get a properly specified regression model, the following tests were performed to compare between the ordinary least squares regression (OLS) model and geographically weighted regression (GWR) model: corrected Akaike Information Criteria (AICc), Adjusted R^2 and Global Moran's I for residual. Accordingly, the model with lower AICc value indicates a closer approximation of the model to reality (Wang et al. 2005). Higher Adjusted R^2 represents that the regression model can account for more dependent variable variance (Gao and Li 2011). Moran's I was calculated to quantify the spatial autocorrelation of model residuals for OLS and GWR, if significant spatial autocorrelation in model residuals was identified, the OLS model predictions are biased due to ignoring the potential spatial factors and its efficiency should be suspect. In addition, the statistical significance of the spatial variation in GWR model is also tested by a Monte Carlo simulation. In order to improve the understandability, an overview of the study framework is presented in Figure 2.

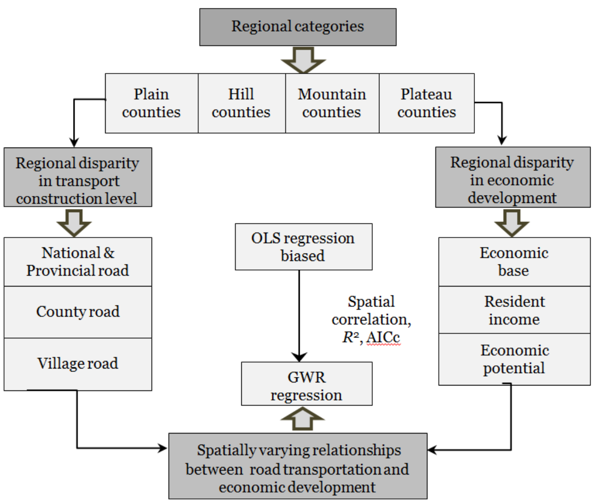

Figure 2 Framework structure of the article.

1.3 Data source

Data on each grade road were obtained from Sichuan Province highway bureau (2006-2015); social-economic indicators are derived from Sichuan province Statistical Yearbook (2006-2015) and Panzhihua Statistical Yearbook (2006-2015), the partially missing values were estimated from the average growth rate of five years. Based on comparable price in 2000, all the value variables are converted, the average values of each indicator from 2006 to 2010 are regarded as the data for the "11th Five-Year Plan", similarly, data for the "12th Five-Year Plan" were obtained based on average values from 2011 to 2014 (the latest data only update to 2014). Data of county classification indicators including elevation, slope and relief amplitude were derived from SRTM (Shuttle Radar Topography Mission) DEM Digital Elevation Database for the mainland China, which has a 90m resolution as calculated by ArcGIS10.1 spatial analysis module. Due to the adjustment of administrative divisions in the study period, this paper takes 181 counties as objection in 2006, excluding new districts and administrative counties.

2 Results

2.1 Spatial distribution of economic development

An economic index is the reflection of the productive capacity of a region. Figure 3 showed strong inequalities of economic development in each geomorphic county.

The composite economic index in plain counties performed much better than others. During the two Five-Year Plans economic index was 0.249 and 0.258 respectively, increased by 3.61%, owing to the preponderant in geographical location (lie in the middle of Sichuan basin) and the highly developed non-agricultural industry, this region possessed a superior economic foundation, occupied 52.55% of the entire provincial economic output. However, hill counties maintained relatively lower composite economic value, merely 52% and 53.4% respectively of plain areas relating to the first and second study period. The traditional energy and chemical industry played a guiding and supporting role in economy. Due to fewer social fixed assets investment and massive deficit of local governments, the potential of regional economy was impeded. Mountain areas faced with gradual revitalization in economy, to a large extent, are rich in natural resources, own large farmland area, fertile soil as well as hydropower and mineral resources, moreover, there is great potentiality for the exploitation of tourism industry. With regard to plateau regions, economic development level ranked the last, most of which is owing to the unreasonable industrial structure.

Furthermore, economic imbalance between the four geomorphic counties have been narrowing, CV index of composite economic index among them was 0.429 during the "11th Five-Year Plan", while the ratio decreased to 0.355 during the "12th Five-Year Plan". In view of the internal differences among each region, all of the four counties decreased. Apparently, plain counties showed a large dispersion, followed by mountain counties and economic gap in plateau counties was the smallest.

2.2 Spatial distribution of road transport infrastructure

Figure 4 shows the current distribution of road transport infrastructure across regions during the two Five-Year Plans. In general, plain and hill counties have the characteristics of convenient transportation condition, while mountains and plateaus with sparse and poorly road infrastructure. Large gradient variations existed in the density and quality of road facilities, gap was mainly reflected in the construction level of County and Village roads.

In the course of research time, National & Provincial road density increased at a much lower growth rate and showed little regional difference. Conversely, County and Village roads were unequally distributed among different regions. Spatial distribution of County road construction level dropped off linearly with increasing elevation. Plain areas with the highest County road density, reached 66.55 km/10² km² of land in the "11th Five-Year Plan" and rose to 70.22 km/10² km² of land in the "12th Five-Year Plan", 19.75 and 20.69 times more than plateaus, demonstrating the expanding regional differentiation. With the implementation of "village to village access" project, infrastructure of Village roads has seen a significant increase in these years, the performance of plain counties ranked the first, with 105.66 km/10² km² of land during the "12th Five-Year Plan", 22.93 times than plateau counties. Parallel with this development, construction of Village road

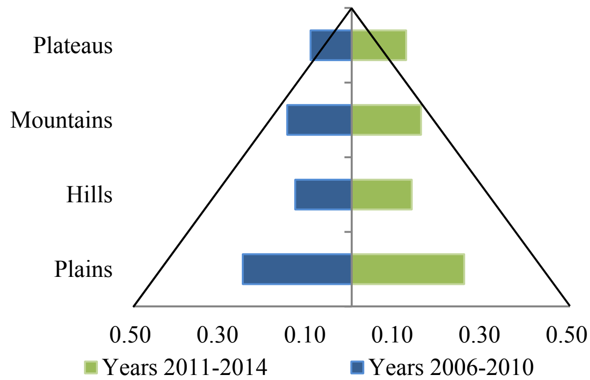

Figure 3 Composite economic index in each geomorphic county in Sichuan province, China.

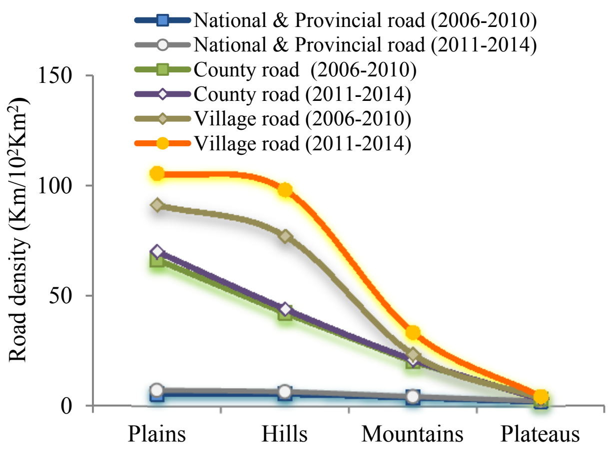

Figure 4 Spatial distribution of road transport infrastructure in Sichuan province, China.

in hill counties has increased markedly by 41.88%.

Therefore, the disparity of Village road in the four geomorphic counties was on a decreasing trend while National & Provincial roads as well as County roads were expanding.

2.3 Effect of road transport infrastructure on economic development

2.3.1 Relationships between traffic factors and economic development obtained by OLS

The ordinary least squares regression (OLS) was firstly carried out (Tables 3 and 4); the variance inflation factor (VIF) of all the candidates indicated no bias due to multi-collinearity and were kept in the model. Adjusted R^2 of the regression equations based on OLS showed that 43% and 47% respectively of the variation in economic development could be explained by the explanatory variables in the two Five-Year Plans. Accordingly, the *F* value in OLS model indicated that the overall model is significant. According to t-probabilities (Table 4), all variables except National & Provincial roads in the "11th Five-Year Plan" were statistically significant above the 95% confidence level. In particular, National & Provincial road was the most sensitive factor, displaying negative coefficients in the "11th Five-Year Plan" while exerting positive influence in the "12th Five-Year Plan". Moreover, unlike the County road, National & Provincial road played a positive effect on the economy during the study time, while negative correlation between Village road and economic development has been detected.

2.3.2 Relationships between traffic factors and economic development explored by GWR

The local estimated values of independent variables were derived from the mixed GWR model. In the study period, both of the local models were statistically significant (P<0.01) (Table 4). Adjusted coefficients of determination (Adjusted R^2) in GWR were 0.63 and 0.65 respectively in the two Five-Year Plans.

In respect of mean coefficient, each variable was smaller than that of OLS model (Table 4), indicating that under the spatial interaction, transport infrastructure produced spillover effects on other geographically adjacent regions, thus obtained lower elasticities. During the two Five-Year Plans, all of the variables had both positive and negative coefficients, suggesting the varying effects on economy. Moreover, the results of Monte Carlo test for the GWR model (Table 4) further certified significant spatial non-stationarity (P <0.01) of all the independent variables. Thus, the effect of road transport infrastructure on economic development is heterogeneity on the basis of the geographical location. The Coefficient of National & Provincial road showed the highest range, from -3.015 to 3.494 during the "11th Five-Year Plan", and ranged from -1.002 to 2.094 during the "12th Five-Year Plan". Village road, however, had a relatively small coefficient range.

Table 3 Diagnostic information of ordinary least squares regression (OLS) and geographically weighted regression (GWR) model

Parameter	"11th Five-Year Plan" (2006-2010)		"12th Five-Year Plan" (2011-2014)	
	OLS	GWR	OLS	GWR
AICc	-315.517	-377.686	-358.017	-428.945
R^2	0.423	0.718	0.445	0.725
R^2Adj	0.41	0.636	0.433	0.657
Moran's I	0.286	0.010	0.3653	0.09314
F	43.331	3.958	47.333	4.274
P	0.000	0.000	0.000	0.000

2.3.3 Fitness of GWR model

The statistical comparison between the two models revealed that there is a significant improvement in prediction by applying the semiparametric GWR method (Table 3). The adjusted R^2 in GWR model were 22.6% and 22.4% better compared to the OLS model in the two Five-Year Plans. Additionally, AICc value of the GWR model decreased by 42.5 in the "11th Five-Year Plan" and 51.26 in the "12th Five-Year Plan" compared with OLS model. Usually, a decrease of AICc values lower than three indicates the model with the lower AICc is held to be a better fit (Gao and Li 2011), and examination of the OLS residuals showed that they were spatially clustered and correlated. Thus, a violation of the assumption of OLS regression was measured, whereas model residuals of the GWR models generally present rather low autocorrelation. All these results determine the performance of GWR model is superior to the global model.

Table 4 Summary results of the Ordinary Least Squares regression (OLS) and Geographically Weighted Regression (GWR) model

Period	OLS				GWR		
	Parameters	Coefficient	*t*	VIF	Mean coefficient	Range	*P*[1)]
"11th Five-Year Plan" (2006-2010)	Constant	0.1019***	6.716***		0.113	-0.044~0.248	0.000***
	N&P road	-0.304 n/s	-1.371 n/s	1.065	0.008	-3.015~3.494	0.000***
	County road	0.300***	10.241***	1.631	0.075	-0.817~0.426	0.000***
	Village road	-0.054**	-2.323**	1.704	0.012	-0.393~0.307	0.000***
"12th Five-Year Plan" (2011-2014)	Constant	0.097***	7.296***		0.067	-0.131~0.191	0.000***
	N&P road	0.399**	2.496**	1.107	0.559	-1.002~2.094	0.000***
	County road	0.249***	10.335***	1.532	0.159	-0.214~0.418	0.000***
	Village road	-0.055***	-3.222**	1.51	-0.011	-0.336~0.097	0.000***

Notes: VIF= Variance inflation factor; N&P road= National & Provincial road. ***significant at 0.01 level; **significant at 0.5 level; *significant at 0.1 level. n/s: not significant; [1)] Monte Carlo test (Fotheringham et al. 2002).

Table 5 Geographically Weighted Regression (GWR) estimated results in each geomorphic county

	"11th Five-Year Plan"(2006-2010)				"12th Five-Year Plan"(2011-2014)			
	Intercept	National & Provincial road	County road	Village road	Intercept	National & Provincial road	County road	Village road
Plains	0.116 (+100%)	-1.013 (+23.53% -73.47%)	0.198 (+75.51% -24.49%)	0.026 (+65.31% -34.69%)	0.031 (+73.47% -26.53%)	0.128 (+51.02% -48.98%)	0.235 (+100%)	0.036 (+69.39% -30.61%)
Hills	0.075 (+92.31% -7.69%)	0.038 (+76.92% -23.08%)	0.095 (+71.79% -28.21%)	-0.006 (+46.15% -53.85%)	0.016 (+69.23% -30.77%)	0.764 (+94.87% -5.13%)	0.140 (+100%)	0.015 (+66.67% -33.33%)
Mountains	0.129 (+100%)	0.367 (+63.74% -36.26%)	-0.006 (+60.44% -39.56%)	0.016 (+58.24% -41.76%)	0.108 (+100%)	0.740 (+79.12% -20.88%)	0.124 (+80.22% -19.78%)	-0.046 (+43.96% -56.04%)
Plateaus	0.097 (+100%)	1.827 (+100%)	0.132 (+100%)	-0.022 (+50% -50%)	0.181 (+100%)	-0.593 (-100%)	0.184 (+100%)	-0.003 (+50% -50%)

Notes: Content outside brackets represents the mean coefficient in the corresponding region; "+" indicates the proportion of counties with positive coefficient; "-" implies the negative influence ratio of counties.

2.3.4 Spatially varying relationships between road transport infrastructure and economic development

In view of the considerable disparity in economic development and road infrastructure construction level among the four geomorphic regions under study here, we can reasonably expect that output elasticities of traffic factors take very different values on economic development for each of these regions. Sequentially, the local estimates for traffic variables in the sub-region were computed (Table 5), moreover, coefficient distribution maps both in the horizontal (Figures 5, 6, 7) and vertical (Figures 8, 9, 10) dimensions were drawn up. Those maps further highlighted that the association between economic development and road transport infrastructure varied dramatically across the study area.

(1) Coefficient variation of National & Provincial road

The national & provincial road is the arterial high-grade highway of the most profound economic and political significance. It is the most important link between the capital and provinces, autonomous regions and municipalities or between provinces, forming the skeleton of the regional highway network and taking on the main tasks of regional transportation.

The relationship between National & Provincial road and economic development level exhibited a great spatial non-stationarity (Figures 5 and 8), with an elasticity coefficient gradually increased from the negative estimates in low plain counties to positive values in high western mountain counties.

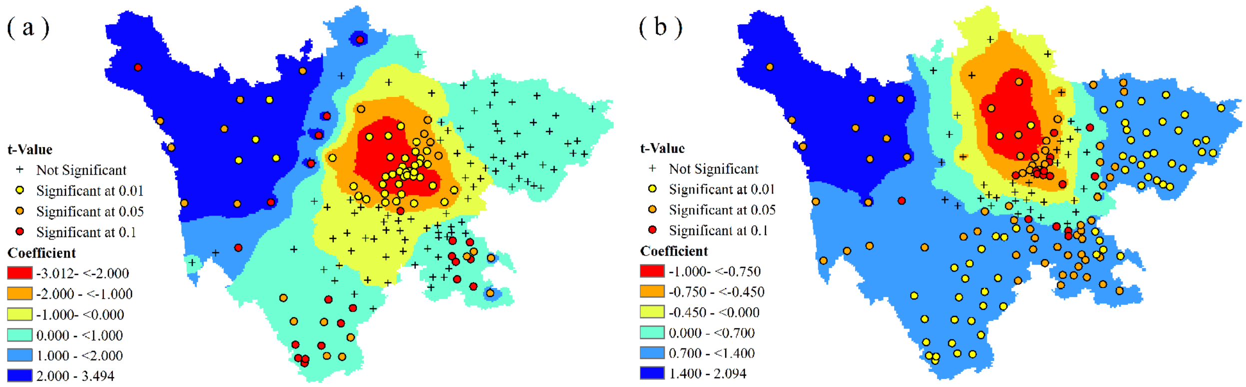

Figure 5 Spatial distribution of National & Provincial road coefficient and its *t*-value for the years 2006-2010 (a) and 2011-2014 (b).

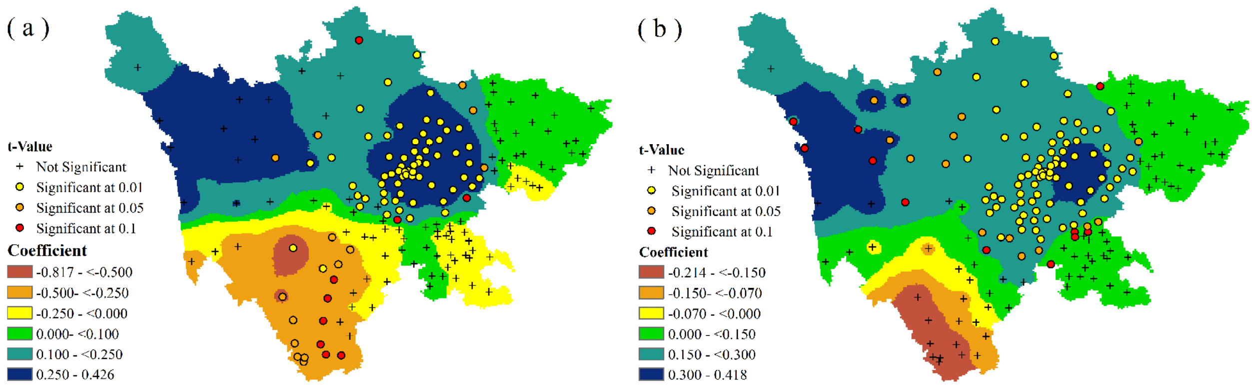

Figure 6 Spatial distribution of County road coefficient and its *t*-value for the years 2006-2010 (a) and 2011-2014 (b).

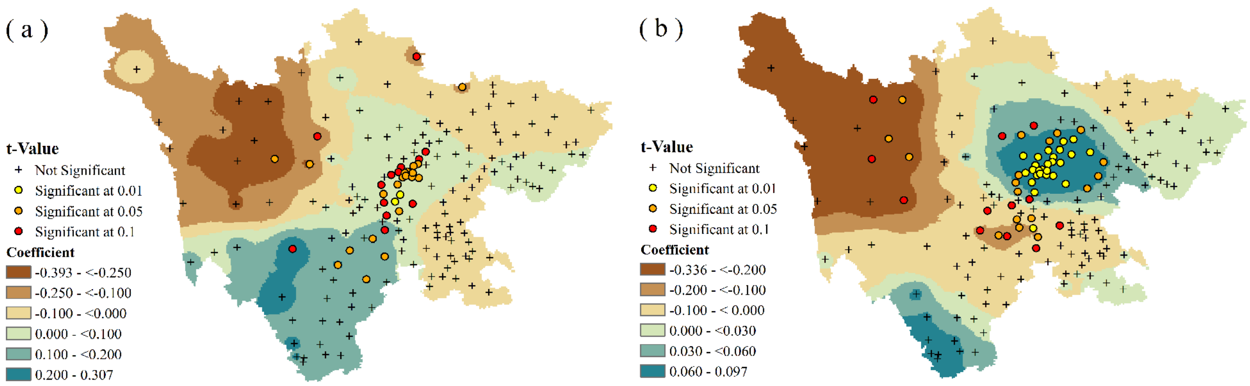

Figure 7 Spatial distribution of Village road coefficient and its *t*-value for the years 2006-2010 (a) and 2011-2014 (b).

According to mean value estimated by GWR (Table 5), a negative correlation was found in the plain counties during the “11th Five-Year Plan”, implying the construction of National & Provincial road was inadequate at that time. On the contrary, a positive influence was observed during the “12th Five-Year Plan”, this may be due to the strategies of integrated development between Chengdu-Chongqing economic zones from 2011, benefiting from the coordinated inter-regional traffic construction, which accelerated the flow of various production factors. Local coefficients for plain counties ranged from negative to positive during the two periods, 51.02% and 26.53% respectively of the plain counties exhibited statistically significant negative parameter estimates, mainly concentrated in metropolitan and surrounding counties. It is reasonably acceptable that in the process of the

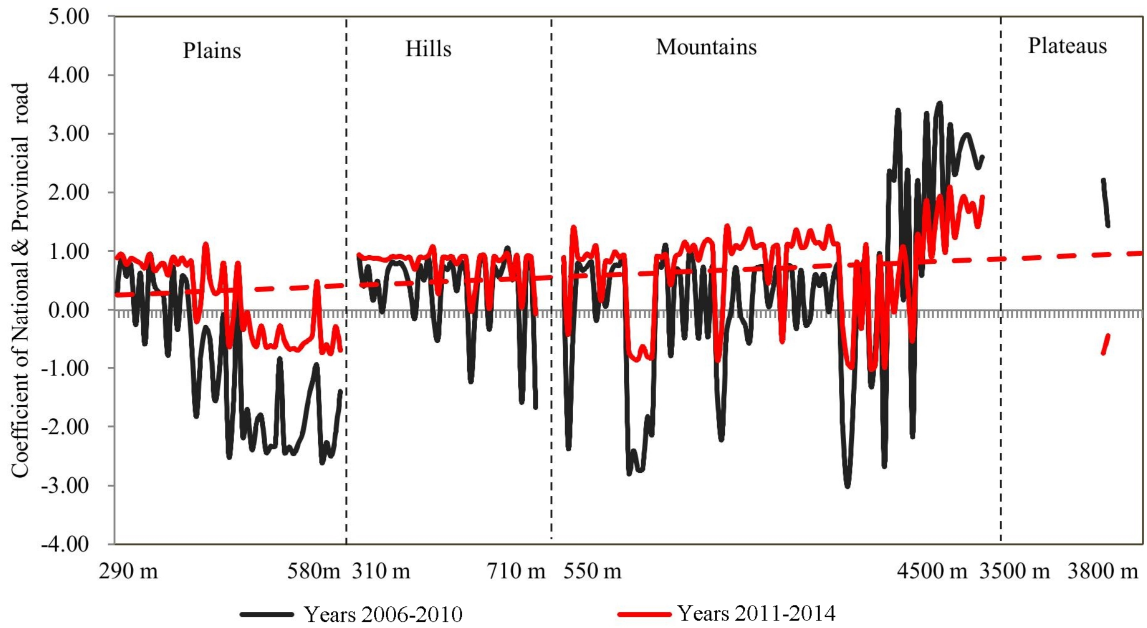

Figure 8 Gradient variations in the coefficient of the National & Provincial road.

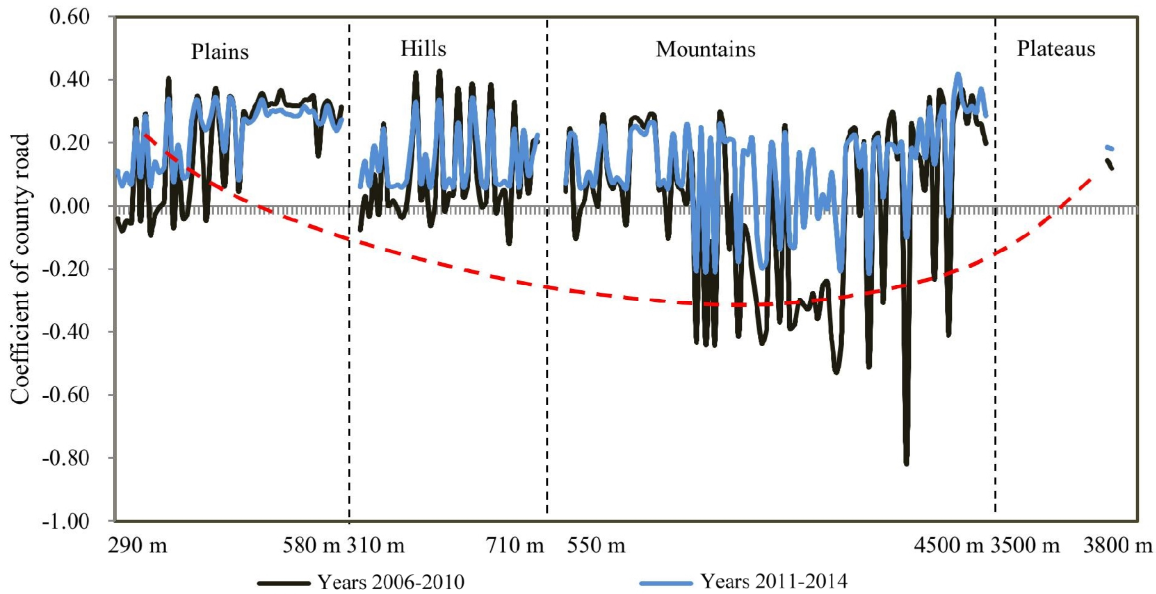

Figure 9 Gradient variations in the coefficient of the County road.

rapidly developed urbanization, demands for well-developed traffic system become serious, while the improved outbound traffic conditions lag behind the increased demand of economic development.

In terms of hill counties, the National & Provincial road played a continuously improved effect on economy, elasticity values indicated that a 1% increase in high grade road density averagely generated 0.04% composite economic growth in the first period of study. It rose to 0.76% in the second period, similar to plain counties; a mixture positive and negative effects was observed in hills, proximately 76% of hill counties presenting positive coefficients in the "11th Five-Year Plan". The ratio increased to 95% in the "12th Five-Year Plan", with 16.66% and 81.19% respectively was found to be significant at the 0.1% level, demonstrating more investments are being poured into these projects, much economic benefits will be created.

With respect to mountain counties, National & Provincial roads were a positive influential factor,

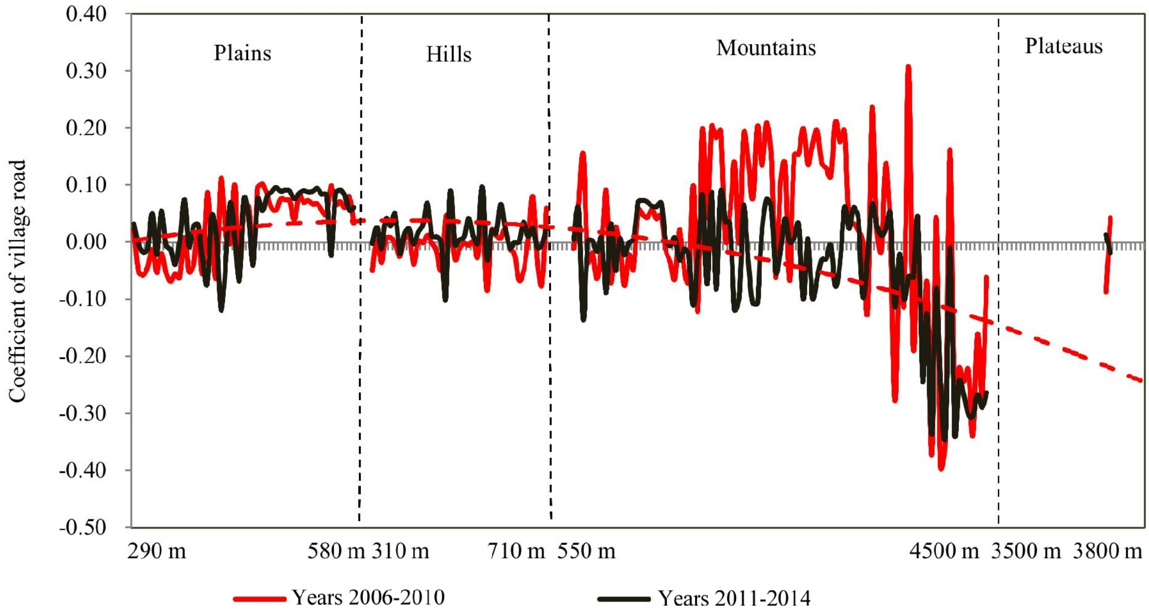

Figure 10 Gradient variations in the coefficient of the Village road.

with a 1% increase of the high grade road density, averagely promoted 0.37% and 0.74% respectively in economic growth for the two periods. For the local parameter estimates, 37.36% of the mountain counties had a significant (P<0.1) positive influence on the response variable during the "11th Five-Year Plan", and the ratio rose to 70.33% during the "12th Five-Year Plan", the strength of the positive relationships was generally higher in the western high altitude part. It is clear that a new round of transportation propulsion projects in the west mountain area during the decades largely enhanced the connection between peripheral areas and developed zones. It thus provided more opportunities for economic growth. Comparing plains with hills, coefficient range in mountain counties was higher, which indicates more spatial discrepancy of the high grade road in this area. This could be due to the inconsistent relationship between traffic construction level and economic development in mountains.

National & Provincial roads yielded the highest economic returns in plateau counties during the "11th Five-Year Plan", producing economic multiplier effect, and the unanimous positive estimates demonstrated that increasing high grade road is conducive to boost economic growth in both of the two plateau counties, whereas this variable exhibited an inverse influence during the "12th Five-Year Plan", the reason account for this include two aspects. Firstly, as a part of the ecotourism circle in west Sichuan which has been provided by the provincial government recent years, nevertheless, the inner loop highways were still absent, resulting in higher travel cost and lower tourism appeal. Secondly, serious inadequacies on the main-line highway became one of the key restraints in holding back the tourism travel market. These two factors consequently hindered the development of interregional tourism as well as economic growth.

(2) Coefficient variation of County road

The County road is the highway connecting the county with the main townships, commodity production and distribution centers. The basic function of the County road is to distribute the trunk traffic flow and played important role in the short-distance transportation.

The spatially varying relationship between County road and composite economic index also be identified, the positive influence circle concentrated both in Chengdu plain and the northwest mountain, the negative influence circle centered in southwest mountain (Figure 6). Meanwhile, on the vertical dimension, a U-shaped relationship was found in the four regions (Figure 9).

The County road had a larger influence on the plain counties where land is flat and industry intensive, 1% increase of County road density, promoting 0.19% economic growth by an average in the "11th Five-Year Plan" and the elasticity reached 0.235% in the "12th Five-Year Plan". Additionally, the local estimates ranged from negative 0.09 to positive 0.41 in the former Five-Year Plans, 87.18% of the plain counties showed significant (P<0.1) positive influence. Subsequently the unanimous positive coefficient was observed for the entire plains category during the "12th Five-Year Plan". This indicates that investment in County road among plain counties should be taken as a priority in determining policy. County road takes on the function of the linkage between provincial trunk and rural ways, promoting the economic connection between counties, which is of benefit for the resource-consuming industries that shift from plains to other advantageous areas, and further stimulates mutually complementarity in regions.

Compared with plains, the County road played a minor role in driving economic development in hill counties. The mean elasticity indicated that a 1% increase in the density of County road resulted in a 0.095% and 0.14%, respectively, economic improvement by average during the first and second period, implying that County road performed as an extraordinary driving force to extend industrial chain between hill counties, effectively spurred the economic growth. Additionally, the influence of County road varied from positive to negative correlations among hill regions during the "11th Five-Year Plan", while the regression coefficient for the County road was positive for the entire hills in the "12th Five-Year Plan". This demonstrated a decreasing spatial difference which is the result of narrowing internal disparities both in transport infrastructure construction and economic development.

The smallest influences were detected in mountain counties, a cluster of negative coefficients in the "11th Five-Year Plan". This implied an inverse relationship with economic development. During the "12th Five-Year Plan" mean coefficient turned to positive. This can be mainly ascribed to the comprehensive exploiting strategy in mountain areas, and road transport quality which gradually improved. Meanwhile, coefficients in mountain counties displayed the greatest directional difference in the two Five-Year Plans, the negative estimates pooled in the southwest part, while the central and western mountains showed the highest positive value.

The reason for this is the heterogeneity among mountain counties both in geomorphic condition and regional circumstances, the central mountain with relatively low elevation and convenient location, benefit from the spillover effects of transportation in the heartland. It thus holds more opportunities and tremendous space for economic development. Moreover, in spite of the marginal location and small bases in road infrastructure in western mountains, with a rapid improvement in the County road construction level recent years, a remarkably marginal effect was produced. By contrast, in the context of Panxi urban agglomeration, the driving force of County road seemed to be rather weak, largely due to the poor industry integration in the regions.

The economy in plateaus was positively correlated to County road, and the influence was generally higher in the "12th Five-Year Plan", the coefficient differential between the two plateau counties being small. Owing to the rapid County road construction, a great deal of the labor force was transferred from local places to other places, and the income of residents has greatly increased which is beneficial to the regional development.

(3) Coefficient variation of Village road

The Village road links the administrative villages with towns and chains the villages together. It is the branch of the regional highway transportation not belonging to the township road or the above highway, and it directly services the rural production and living conditions, and is closely related to farmers' income and rural development.

A spatial non-stationarity was also found for the coefficient of Village road. It was characterized by the positive influence circle in the southwest mountains and central plains, whereas the negative influence circles shaped in northwest mountains (Figure 7) in the horizontal direction, Moreover, inverse U-shaped relationship was presented in the four geomorphic counties (Figure 10) in the vertical dimension.

Village road played a major positive role in plains during the study periods. A 1% increase of Village road density almost drove 0.026% economic growth during the "11th Five-Year Plan", and promoted 0.036% economic development during the “12th Five-Year Plan”. Local estimates ranged from negative to positive, suggesting that Village road had varying effects on plain economy. Plain counties showed significant positive influence for the two periods with 40.82% and 48.98% respectively. By way of the “capillary vessel” of transport infrastructure, Village road promotes the coordinated development of urban-rural interaction, inevitably accelerates rural labor migration thereby stimulating off-farm employment and other income-earning opportunities. Furthermore, the availability of Village road infrastructure services accelerates the development of township and village enterprises in plains, opens up markets to rural areas, and stimulates demand for local labor, consequently contributing to the prosperity of the rural economy.

For hill counties, the mean coefficient value showed that Village road was a negative contributor during the “11th Five-Year Plan”, while it was a positive exploratory variable on economy during the “12th Five-Year Plan”. This was greatly attributed to the “village to village access” project, hill counties achieving “leapfrog development” in the construction of Village roads in this time. Moreover, a positive effect of Village road was observed in nearly half of the hill counties for the first period, while majority of them did not pass the significant test (P<0.1). In the second period, local estimates ranged from negative 0.1 to positive 0.1, nearly 70% of hill counties showed a positive influence, 10.26% of them approved by significant testing (P<0.1), mainly distributed near the northeast of Chengdu plain.

The economy in mountains was affected positively by Village road in the first period of study, while the mean coefficient turned to negative during the second period. The map of local estimates of Village road (Figure 7) presented positive influence in the central mountain where they were close to plains, but played slightly weak and negative effect in several scattered portions. Strongly negative influence was found in northwest mountains, and the estimates value decreased with increasing altitude. It showed more spatial differential than the other geomorphic counties (Figure 10). Up to 2014 year, there were 782 villages with less access in Sichuan province, and which were mainly concentrated in western mountains. Apparently, surface engineering construction of roads in high mountains experienced great difficulty, faced with large amounts of investment as well as slow return of income, roads condition in mountain areas was poor. Due to low financial revenue and limited transfer payments, local governments can hardly solve these troubles. Since they can’t meet the needs of economic growth, poverty has been more prevalent in the west mountainous rural communities.

Plateau counties displayed negative mean coefficients during the two Five-Year Plans. It is easy to understand that with poor accessibility in village, enormous benefits have not resulted. Results in substantial loss of perishable agriculture and animal husbandry products occur and ultimately lead to higher transportation cost of products. On the other hand, large numbers of rural settlements in plateaus are relatively dispersed, with low marketization and information-based degree. For a long time, employment pressure of rural surplus labor force has been one of the crucial problems for the areas, which is not beneficial to the steady construction of a new countryside and the livelihood improvement of residents. Similarly, both positive and negative correlations are also observed for this area, with coefficient values from negative 0.09 up to positive 0.04 in the first period, and range from negative 0.02 to positive 0.01.

3 Conclusions and Policy Implications

(1) There were obvious spatial inequalities in the economic development of the four geomorphic counties in Sichuan province, showing a trend of plain counties > mountain counties > hill counties > plateau counties. The gradient differences between them were on the decline, which is conducive to the coordinated development among regions. Comparatively, internal differentiation in plain counties was greatest, followed by mountain counties and the plateau counties was smallest.

(2) The spatial distribution of road facilities also showed obvious imbalance. Plain counties had good road conditions and rapid growth of transport infrastructure, while mountains and plateaus were characterized by poor ground transportation access. Apparently, regional imbalance of road

infrastructure construction level is mainly reflected in County road and Village road while National & Provincial road have little differences. During the study periods, the regional gaps of National & Provincial road as well as County road were constantly expanding while the differences of Village road in the four regions were slowly narrowing.

(3) Higher values of adjusted R^2 and lower AICc values from GWR indicate the improvement in this model performance over OLS. In respect of mean coefficient in GWR model, each variable was smaller than that of OLS model. All variables had both positive and negative coefficients across regions, suggesting the influence of the three traffic factors varied over space.

(4) According to the comparison between the four main geomorphic counties, National & Provincial road generated higher benefits in the high elevation regions than lowlands, which exerted the strongest influence in plateaus during the "11th Five-Year Plan". Hill counties were more sensitive to this high grade road in the course of the "12th Five-Year Plan". In relation to County road, it showed larger influence on the plain counties during the study periods. Village road took an inverse correlation with the economic development in hills and mountains during the "11th Five-Year Plan", and exerted negative influences on the mountainous and plateau economy in the "12th Five-Year Plan". In particular, coefficients of the three grade roads varied greatest in mountain counties.

Such great disparities highlight the need for regions-specific policies for narrowing regional gaps. Firstly, much importance should be attached to the coordinated development strategy between lowland areas and highland regions. Plain counties are supposed to concentrate on the development of advanced industries and pioneer services, transforming the resource-based industries to other regions. In terms of hill counties, speeding up the process of new-type industrialization is one of the important strategic goals. The mountain areas should strive to establish new economic growth poles by wise use of their resource advantages. In accordance with the development of modern agriculture and animal husbandry, agricultural eco-tourism is recommended in plateaus. Secondly, in view of the small scale and poor grade of current transport infrastructure in mountains and plateaus, special emphasis should be given to the expansion of road facilities in these regions, so as to promote the connection between the lagging areas and developed areas, providing the chance for fair development in the backward regions. Thirdly, the sustainable policy framework for road transport development must be tailored according to local realities. These findings suggest that plain areas should endeavor to accelerate regional integration by the construction of transportation networks, and fully exert the corridor values of County road to promote economic cooperation. For hill counties, it is argued that more focus need to be given to the arterial road construction, a prerequisite for industrial belt development. The primary task for mountains and plateaus is to strengthen rural road projects, which is a constraint factor and underlying contributor for these regions; it needs to be point out that high grade road creates more benefits in these lagging areas, and undoubtedly, establishing well connected external transportation is the major factor to reverse geographical disadvantages.

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